NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Biogas and Fuel Cell Opportunities

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Presentation Overview

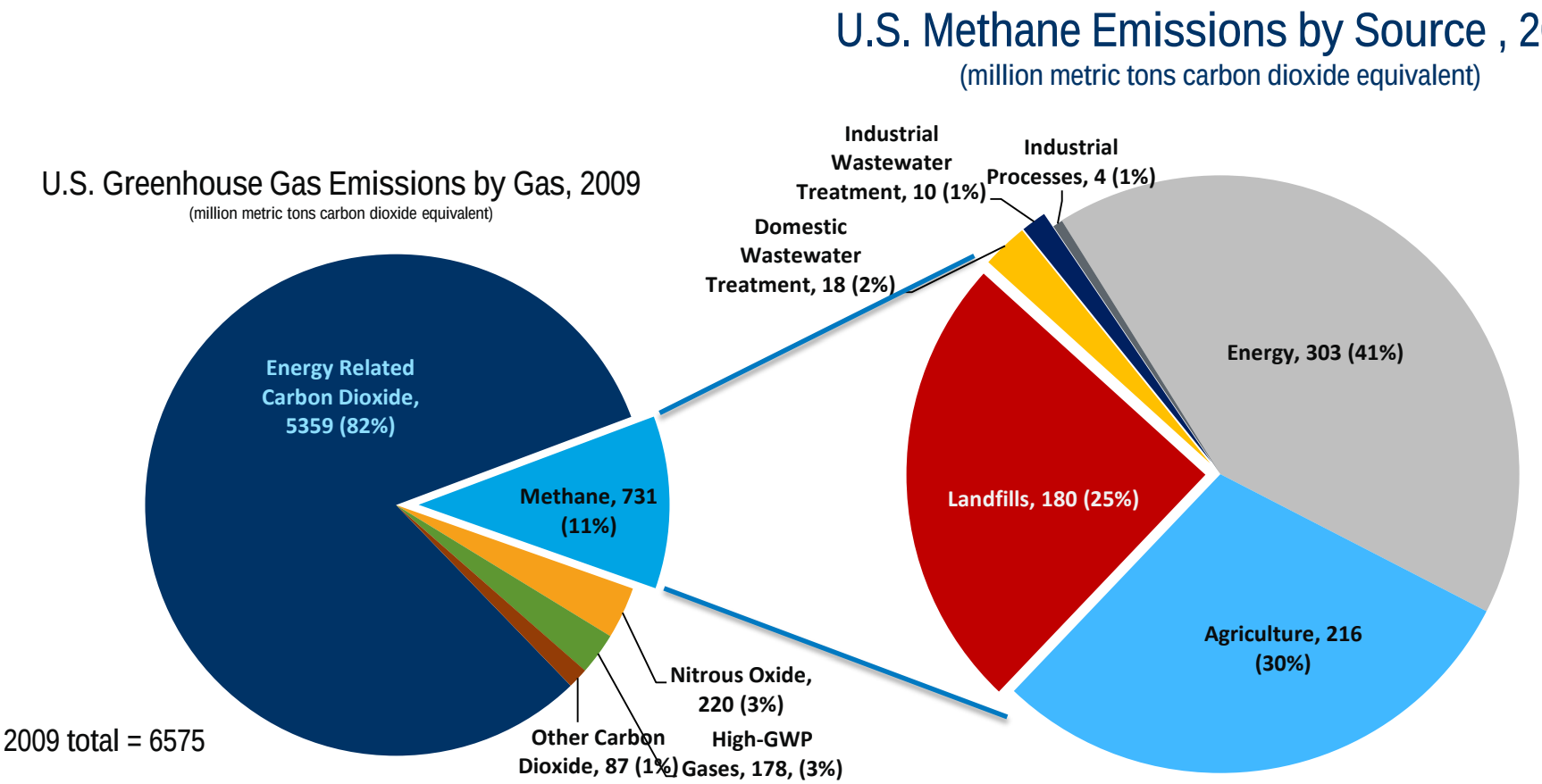
- Fuel cells and the U.S. Department of Energy's Fuel Cell Technologies Office
- Fuel Cell Application Case Studies
- NREL's Fuel Cell Power Model
- Conclusion

Fuel cells and the U.S. Department of Energy's Fuel Cell Technologies Office

Image source: DOE Fuel Cell Technologies Office

U.S. Greenhouse Gas and Methane Emissions

Landfills and Wastewater Treatment contribute ~30% of U.S. Methane Emissions



Source: U.S. Energy Information Administration Emissions of Greenhouse Gases in the United States 2009

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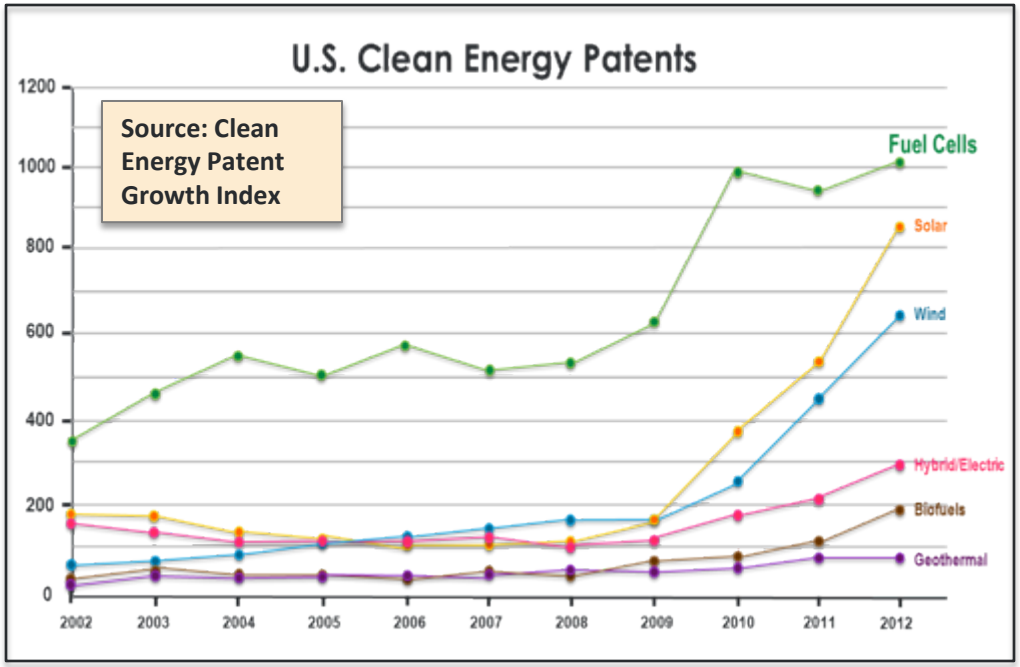
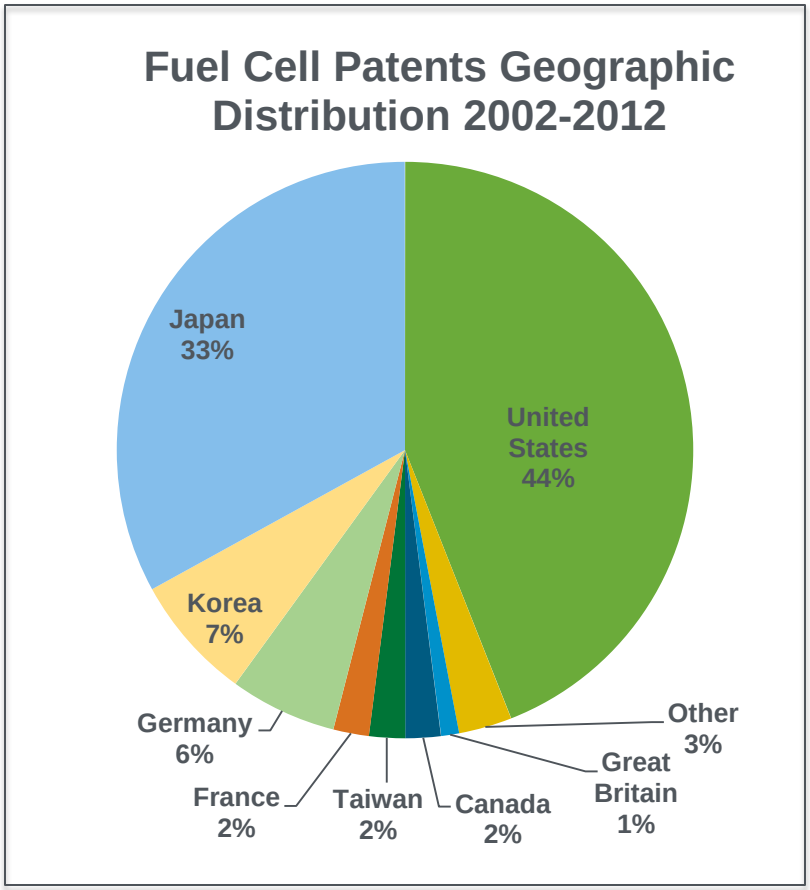
Slide source: DOE Fuel Cell Technologies Office

Fuel Cells – An Emerging Global Industry





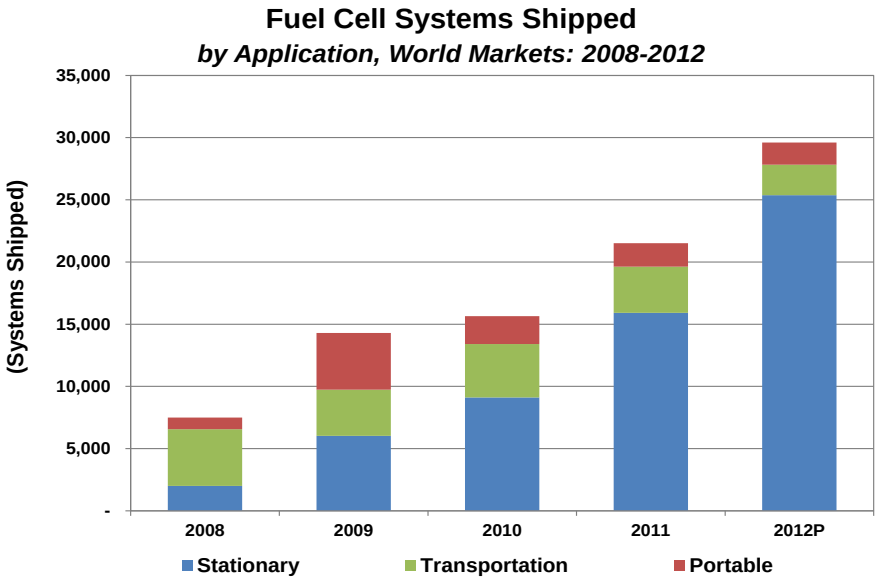
Top 10 companies for fuel cell patents: GM, Honda, Toyota, Samsung, UTC Power, Nissan, Ballard, Panasonic, Plug Power, Delphi Technologies

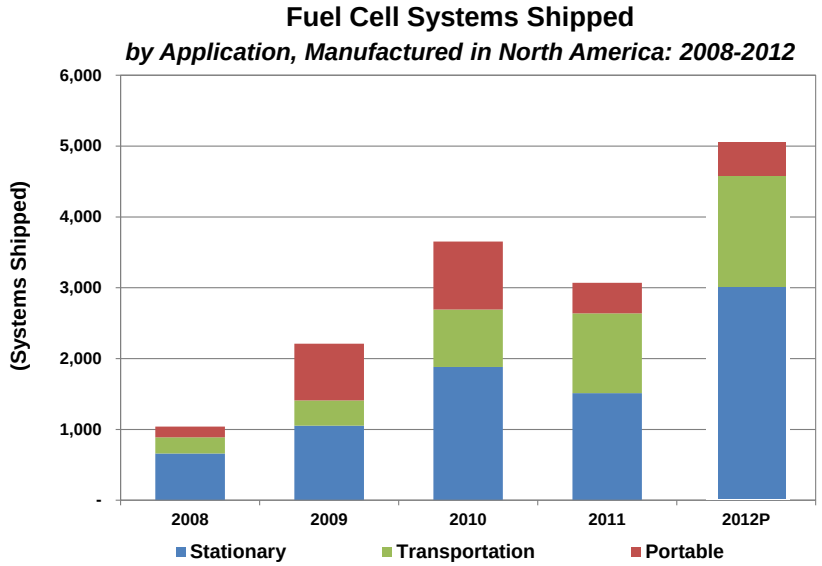
- Clean Energy Patent Growth Index[1] shows growth in all clean energy technology patents
- More than 1,000 fuel cell patents issued in 2012

[1] http://cepgi.typepad.com/heslin_rothenberg_farley_/2013/03/clean-energy-patent-growth-index-2011-year-in-review.html

Slide source: DOE Fuel Cell Technologies Office

Fuel Cell Market Overview





Source: Navigant Research

Market Growth

Fuel cell markets continue to grow

- **48% increase in global MWs shipped**
- **62% increase in North American systems shipped in the last year**

The Market Potential

Independent analyses show global markets could mature over the next 10–20 years, producing revenues of:

- **$14 – $31 billion/year for stationary power**
- **$11 billion/year for portable power**
- **$18 – $97 billion/year for transportation**

Several automakers have announced commercial FCEVs by 2015-2017.

Fuel Cell Technologies Office Mission Statement

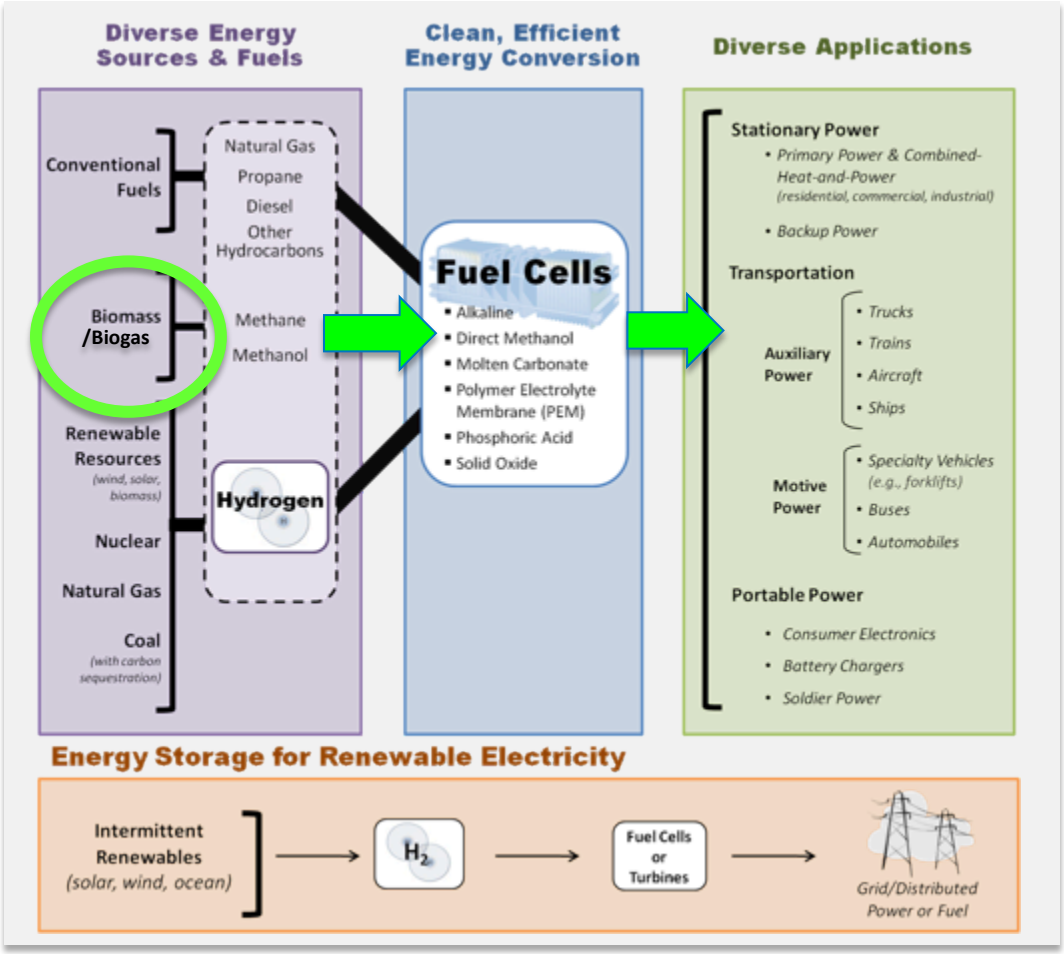
To enable the widespread commercialization of a portfolio of hydrogen and fuel cell technologies through basic and applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges.

For further details and sources see: *DOE Hydrogen and Fuel Cells Program Plan,* http://www.hydrogen.energy.gov/pdfs/program_plan2011.pdf; FuelCells 2000, Fuel Cell Today, Navigant Research

Slide source: DOE Fuel Cell Technologies Office

Fuel Cells Overview and Benefits

The Role of Fuel Cells



Key Benefits

Very High Efficiency
- **up to 60%** *(electrical)*
- **up to 70%** *(electrical, hybrid fuel cell / turbine)*
- **up to 85%** *(with CHP)*

Reduced CO_2 Emissions
- **35–50%+ reductions** *for CHP systems (>80% with biogas)*
- **55–90% reductions** *for light-duty vehicles*

Reduced Oil Use
- **>95% reduction** *for FCEVs (vs. today's gasoline ICEVs)*
- **>80% reduction** *for FCEVs (vs. advanced PHEVs)*

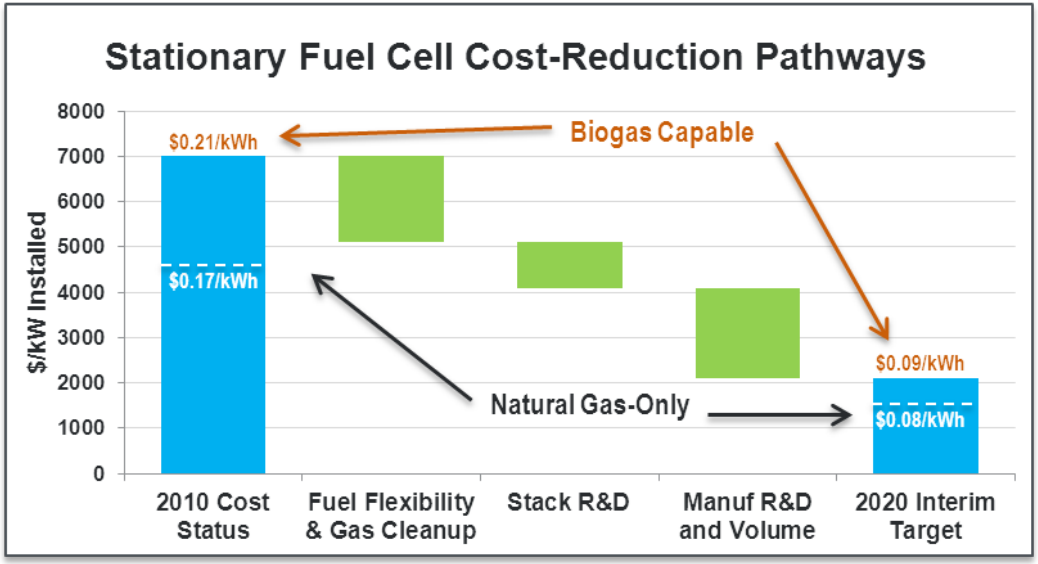
Reduced Air Pollution
- **up to 90% reduction in criteria pollutants** *for CHP systems*

Fuel Flexibility
- **Clean fuels** — *including biogas, methanol, H_2*
- **Hydrogen** — *can be produced cleanly using sunlight or biomass directly, or through electrolysis, using renewable electricity*
- **Conventional fuels** — *including natural gas, propane, diesel*

Slide source: DOE Fuel Cell Technologies Office

Challenges and Strategy: Stationary Applications

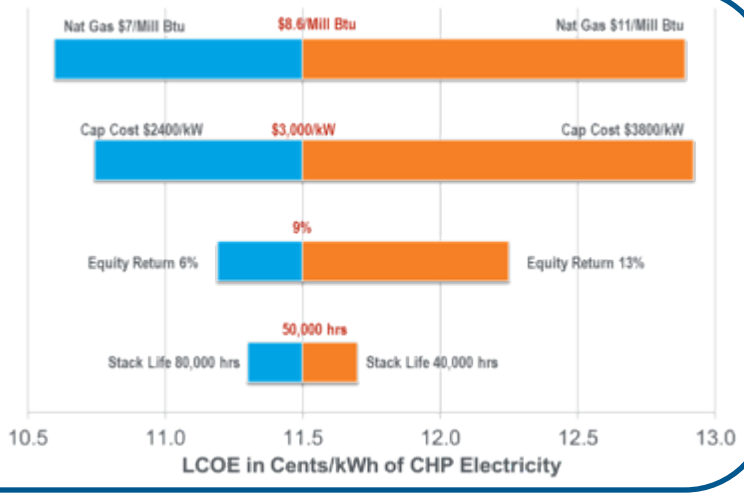
Further reduction in capital cost of medium scale distributed generation/CHP (100 kW – 3 MW) need to be pursued to facilitate widespread commercialization.



- Further reduction of fuel cell system cost required to expedite commercialization
- Natural gas availability and fuel cell performance (efficiency) gains will enhance the technology's market attractiveness
- Development of a cost-effective process for removing fuel contaminants would allow for fuel flexibility
- Also applicable for tri-gen (H_2 production)

Sensitivity analysis around 2015 targets assesses impact of fuel cell system cost and durability on commercialization prospects

Technical Parameters (2015)	
Electric Efficiency (LHV)	45.0%
Combined Effic.(LHV)	87.5%
Size, MWe	1
Operating Life, years	20
Equipment, $/kWe	2,300
Engineering& Installation, $/kWe	700
Fixed O&M, $/MWh	13
Variable O&M, $/MWh	8.0



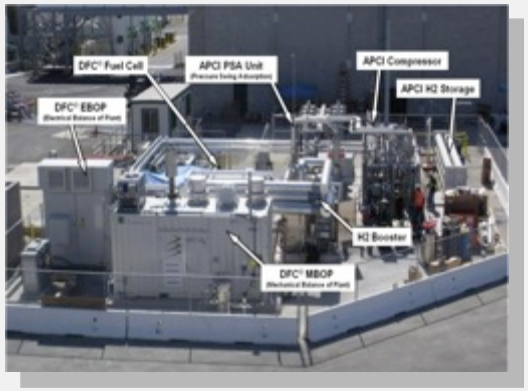
Slide source: DOE Fuel Cell Technologies Office

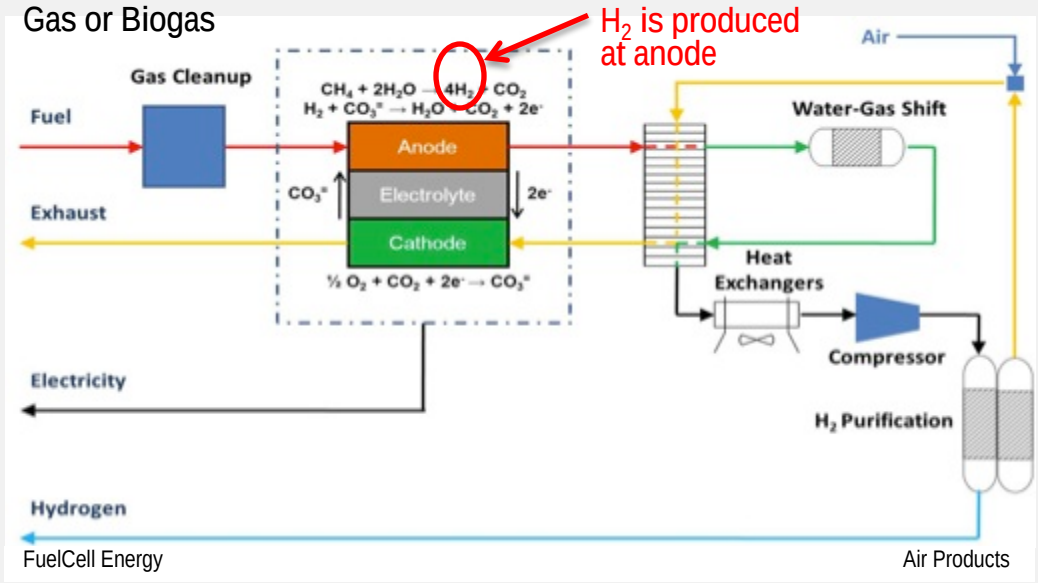
Technology Validation: Tri-Generation

Tri-Generation co-produces power, heat and hydrogen. World's First Fuel Cell and Hydrogen Energy Station demonstrated in Orange County (DOE/FCT project).

Demonstrated world's first Tri-generation station

- Demonstrated co-production of electricity and hydrogen with 54% efficiency
- Uses biogas from wastewater treatment plant





Fountain Valley demonstration

- ~250 kW of electricity
- ~100 kg/day hydrogen capacity (350 and 700 bar), enough to fuel 25 to 50 vehicles.

Slide source: DOE Fuel Cell Technologies Office

DEMO Deployment – BMW Plant

Validate fuel cell powered material handling equipment low-cost hydrogen from land fill gas including performance, operation and maintenance, durability, and reliability under real-world operating conditions.

Project Lead: SCRA

Project Partners:

- **BMW**
- **Gas Technology Institute**
- **Ameresco, Inc.**

Phase 1: Feasibility Study

Completed 26 October 2011

Phase 2: LFG-to-Hydrogen Conversion

8 months nominal; target completion date: July 2012

Critical milestones:

Land, interconnect, start up and test equipment

Monitor hydrogen purity for at least 2 months

Phase 3: Side-by-Side Trial (to be funded)

6 months from satisfactory completion of monitoring portion of Phase 2

Target completion date: January 2013

Critical milestones:

Operate test group of MHE to attain 25,000 run hours

Continue monitoring hydrogen purity of LFG-sourced hydro

Slide source: DOE Fuel Cell Technologies Office

Opportunities for Biogas Applications

Fuel cells operating on bio-methane or hydrogen derived from bio-methane can mitigate energy and environmental issues and provide an opportunity for their commercialization.

Source

Animal Waste

Landfills

Food Processing Waste

Water Treat. Plant

Production & Cleanup

Anaerobic Digester

Biogas

Clean-Up System

Distribution & Utilization

Reformation / Fuel Cell Systems

Biomethane

Injection in NG Pipelines

Power Grid

Electricity

Heat

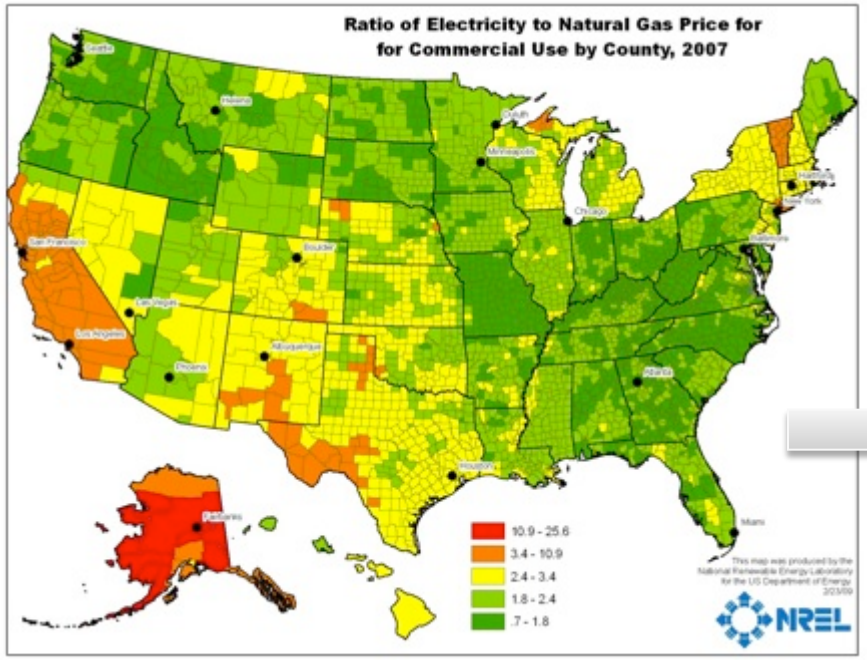
Hydrogen

Vehicle Fueling Station

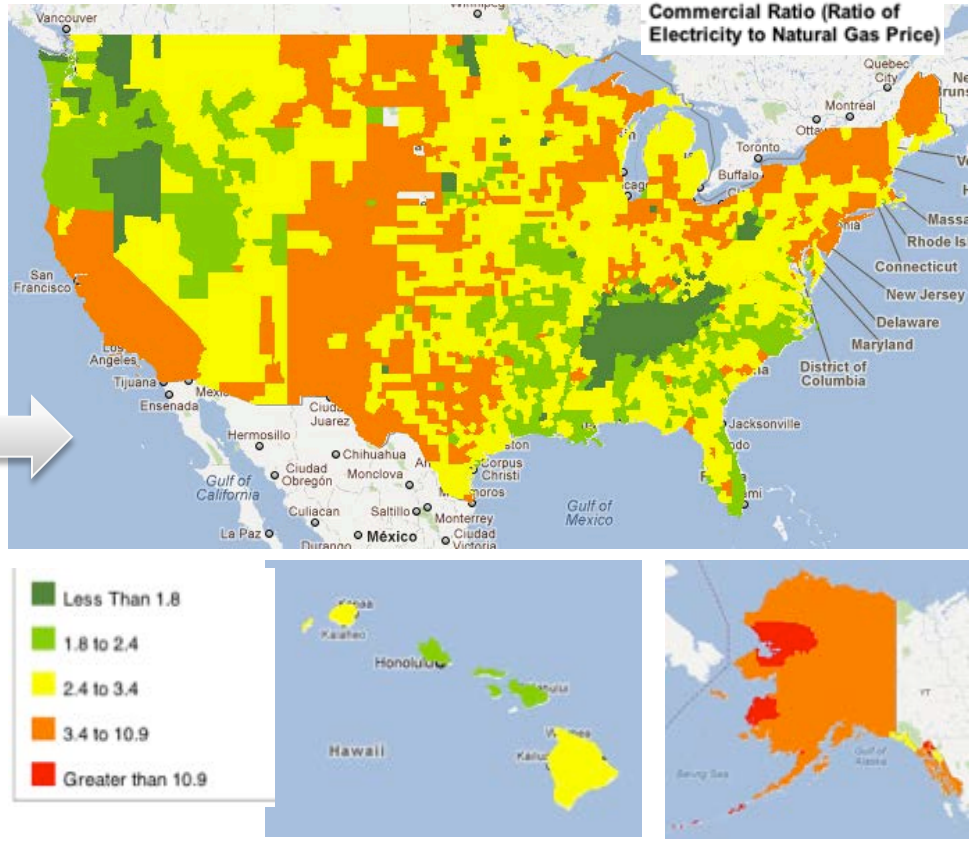
Source: National Renewable Energy Laboratory

Spark-Spread Determines Regional Opportunities for DG from Natural Gas

2007



2010



Spark spread determines regions for favorable use of natural gas

Red/orange regions: High electricity cost, low natural gas cost- favorable for DG

Lower natural gas prices offer increased opportunities for CHP and distributed generation- current vs. 2007.

Source: NREL

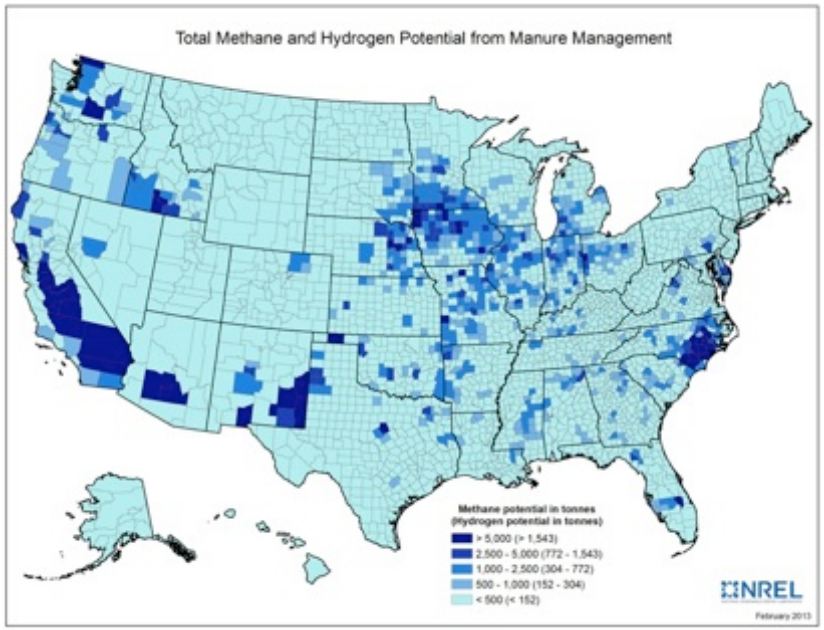
Animal Manure Resource Potential

Animal manure could support upwards of 1% of US vehicle fleet.

Gross CH_4 Potential	1,900 thousand tonnes
Gross H_2 Potential	578 thousand tonnes
FCEV Supported	3.3 million vehicles

FCEV Supported

- 57 miles/gge *10,000 miles driven/yr [10]
- 230 million vehicles in US fleet 2011 [11]



Data Source: USDA 2007 Census [3]

Data: county level only

Animals: milk cows, hogs, broiler chickens

Methane Conversion: EPA State Workbook: Methodologies for Estimating Greenhouse Gas Emissions, Workbook 7 Methane Emissions from Manure Management

Hydrogen Conversion: 3.3 kg CH_4/kg H_2 [9]

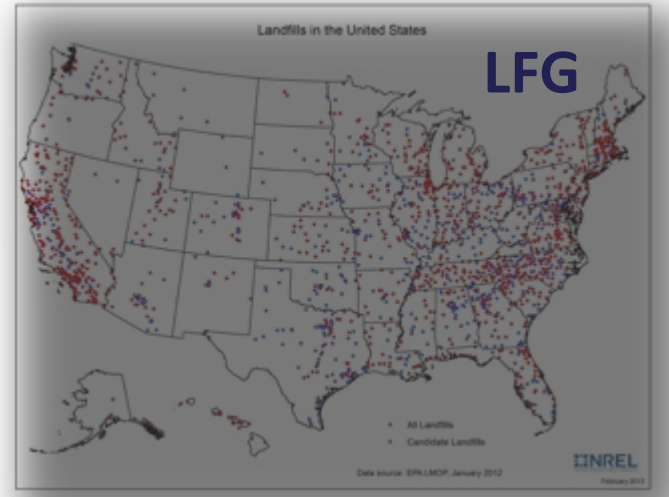
Net Availability: Cross reference to EPA AgStar database of existing anaerobic digesters

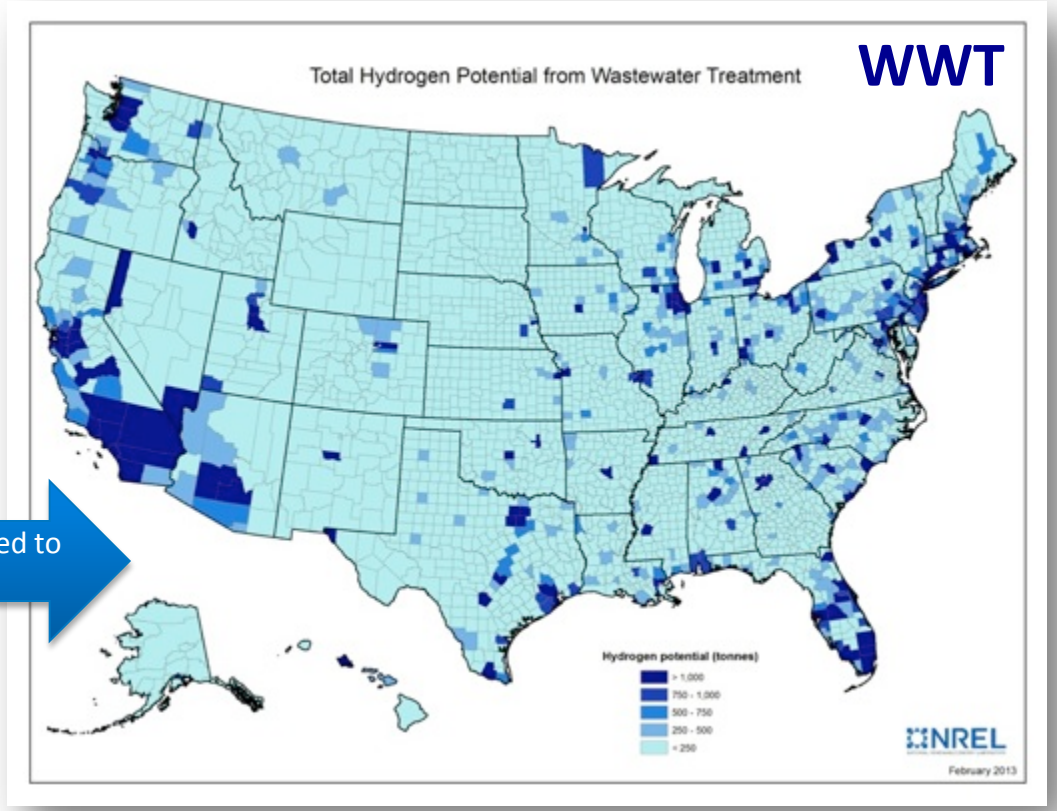
Source: Saur and Milbrandt, *Hydrogen from Biogas: Resource Assessment*, DOE Annual Merit Review Presentation, May 14, 2013, Arlington, VA.

Preliminary Results

Landfill gas and WWT Resource Potential

Point source aggregated to county level





- Combined resource (Manure, LFG & WWT) suggests hydrogen fuel equivalent for approximately 10 million FCEVs
- Net resource estimates are in progress

Preliminary Results

Source: Saur and Milbrandt, *Hydrogen from Biogas: Resource Assessment,* DOE Annual Merit Review Presentation, May 14, 2013, Arlington, VA.

Fuel Cell Application Case Studies

Image source: DOE Fuel Cell Technologies Office

Biogas Opportunities, Barriers and Activities

Opportunities

Biogas from agricultural resources:

- Dairies/food processing
- Other livestock
- Agricultural and forest waste

Biogas from landfills

Wastewater

Biomass-derived natural gas

Barriers

High level of contaminants

High variability of contaminant concentrations

High capital cost for contaminant removal

Low experience level with biogas cleanup

Location of resources relative to demand centers and understanding cost impacts of transportation

Activities

Held workshops to understand gaps for utilizing biogas for hydrogen and power production

Working with Argonne National Laboratory to understand impact of biogas impurities on stationary fuel cell performance

Working with National Renewable Energy Laboratory on location of biogas resources and development of biogas H2A model for biogas cost analysis

Content source: NREL & DOE Fuel Cell Technologies Office

Examples of Fuel Cell CHP Industry Deployments

The Food Industry and Waste Treatment are emerging markets for stationary fuel cells


Source: Gills Onions

Completed Food Producer Deployments:

- **Gills Onions (CA, 600 kW)**
  - 2-300kW fuel cells
  - Generates power for facility @ 47% electrical efficiency
  - Processes ~32 scfm of biogas per fuel cell
- **Sierra Nevada Brewery (CA, 1 MW)**
  - Generates ~100% of brewery's electrical demand
  - Waste heat used for generating steam and boiling beer

Waste Treatment Deployments:

Nine Sites Include

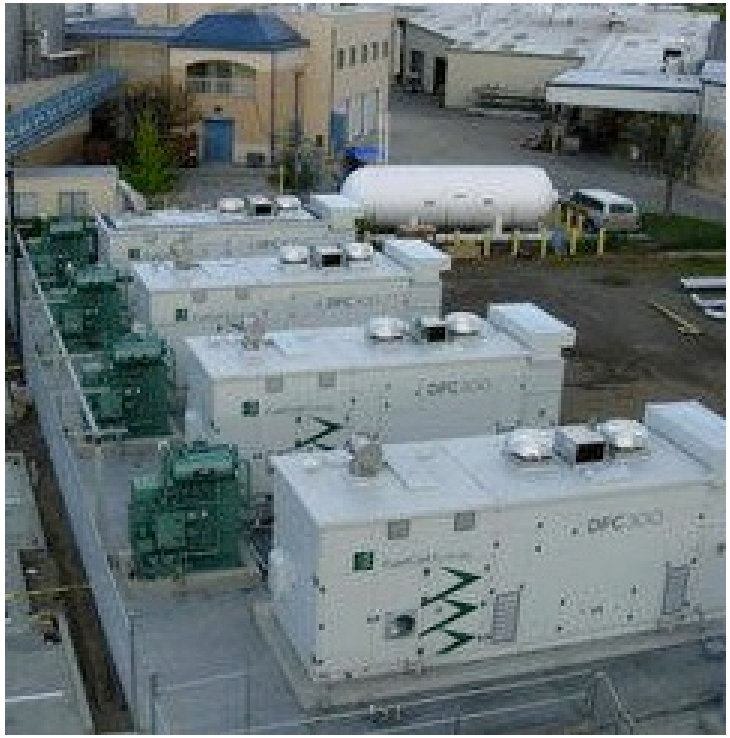
- **Orange County Sanitation District (CA, 300 kW)**
  - 1-300 kW fuel cell
  - Operates on biogas from wastewater treatment plant
  - Produces >100 kg/day of fuel cell grade hydrogen (99.9999% purity)
- **Tulare (CA, 1 MW)**
  - 4-300 kW fuel cells
  - Generates ~50% of waste water treatment plant's electrical demand
  - Waste heat used for anaerobic digestion process

Slide source: DOE Fuel Cell Technologies Office

Case Study: Sierra Nevada

Affordable and reliable power for a brewery

Location	State-of-the-art brewing facility Chico, CA
Date Installed	May 2005
Equipment	• Four 250 kW FuelCell Energy fuel cell power plants fueled with digester gas from the brewing process and natural gas
Use	• Provides nearly all of the brewery's power • Waste heat is used for brewing and other heating needs
Benefits	• 20% savings in energy costs • Doubled energy efficiency • Carbon savings equivalent to removing ~500 cars per year from the road • Excess electricity is sold back to the grid

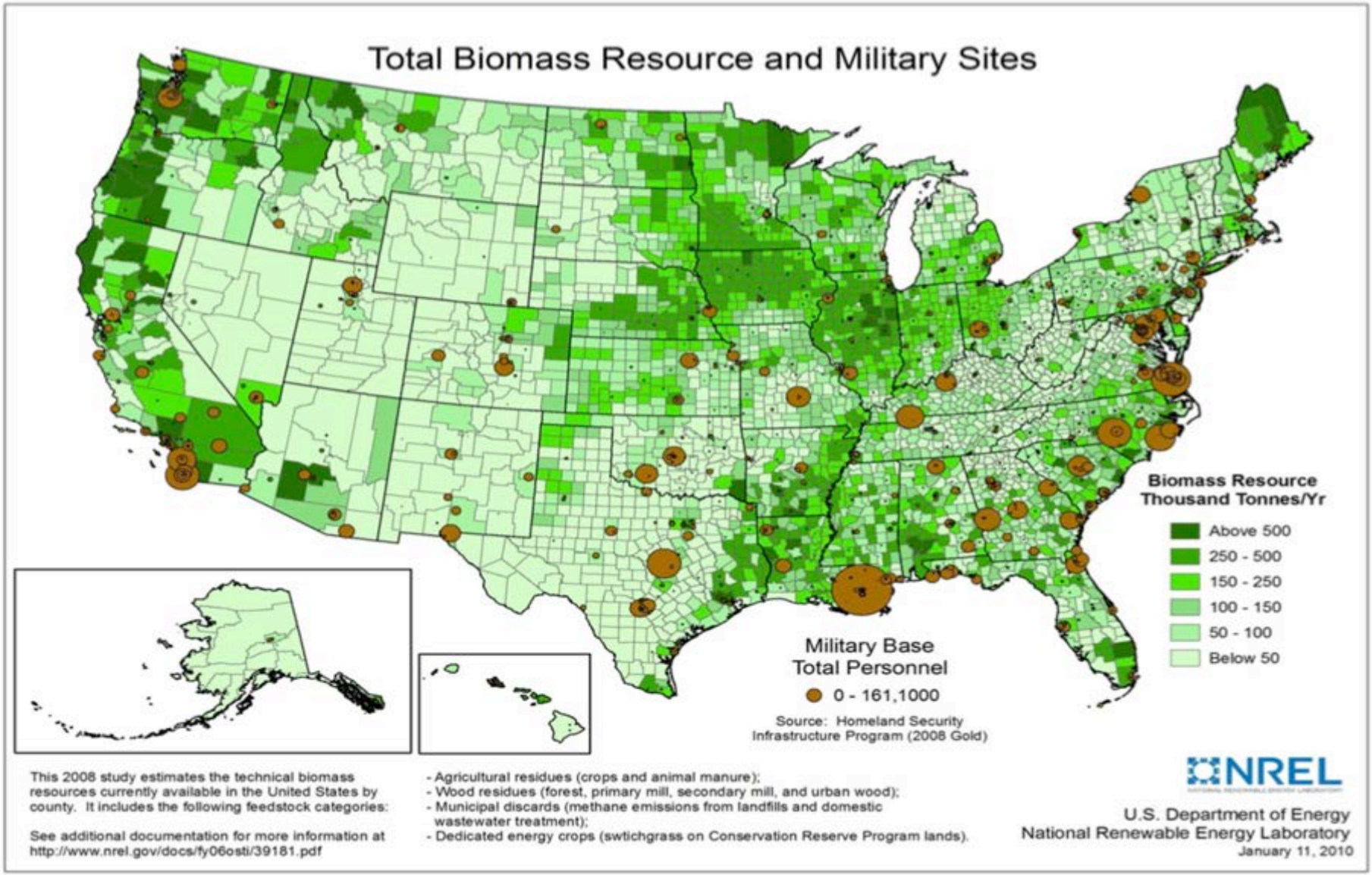


Contact: Bill Foster, bfoster@fce.com, 202-251-7931,

Source: FuelCell Energy

Slide source: DOE Fuel Cell Technologies Office

Potential Resources Near DOD Sites



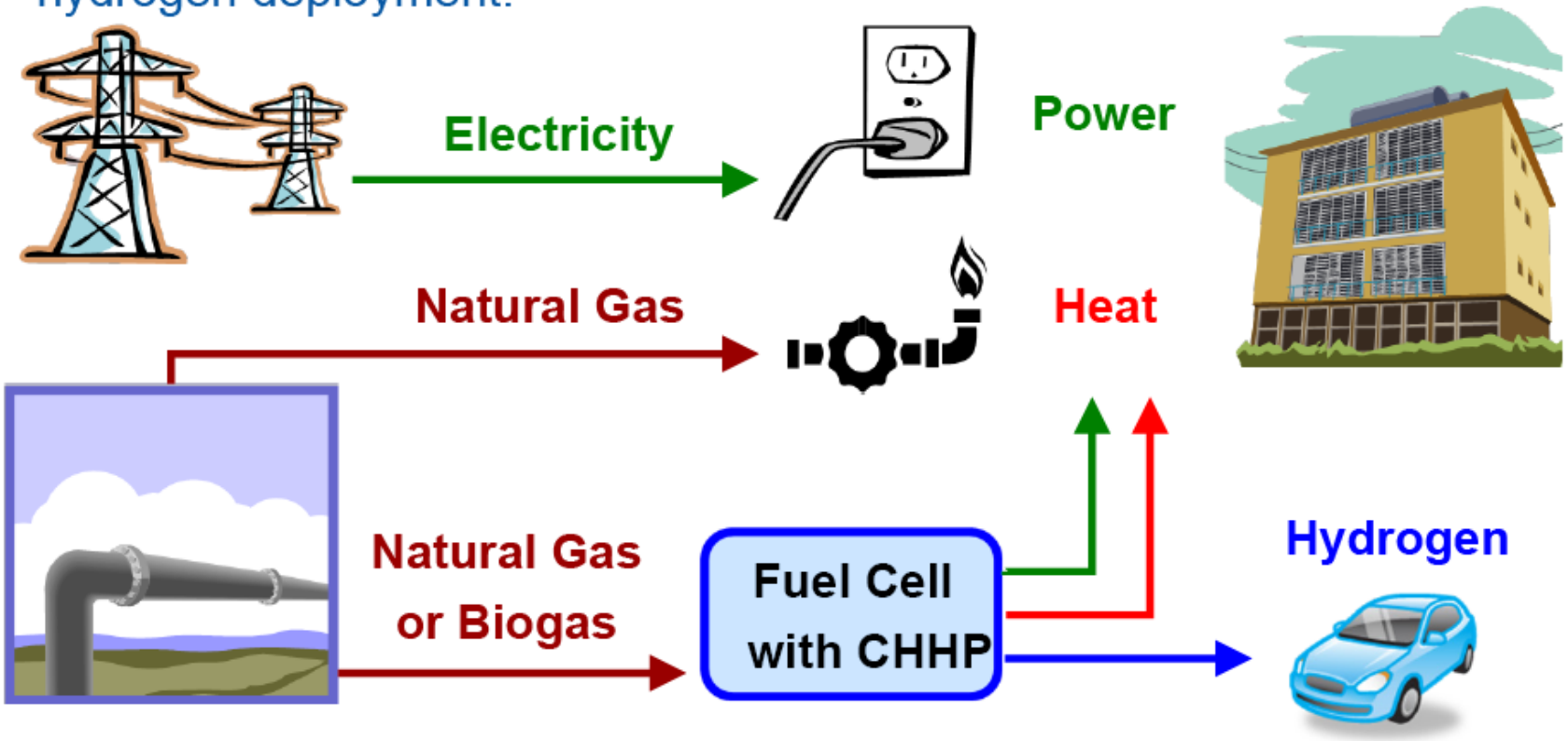
NREL's Fuel Cell Power Model

Image source: DOE Fuel Cell Technologies Office

Fuel Cell Power Model: Overview

Hydrogen infrastructure costs for early transition phase are large, and are relatively high risk due to uncertainty of demand.

The Fuel Cell Power Model allows analysis of combined heat, hydrogen and power (CHHP) systems, which may improve hydrogen deployment.



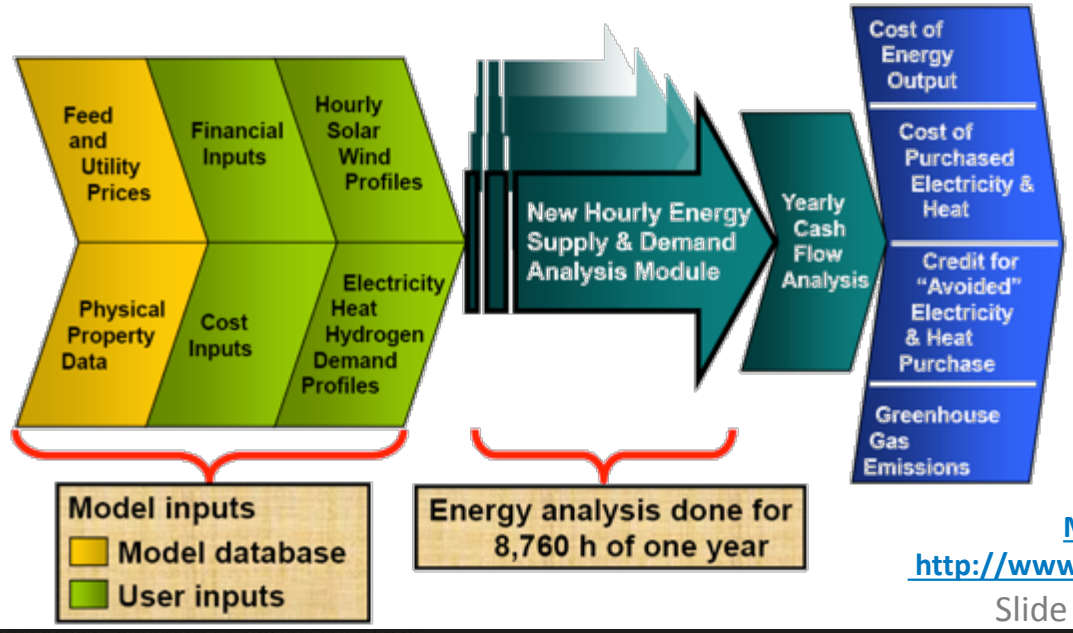
Slide source: DOE Fuel Cell Technologies Office

Fuel Cell Power Model: How it works

Provide a single simple-to-use home for "what-if" business case analysis

Costs have already been gathered & energy analysis is done – now what?

- Calculate cost without IRR
- Simple payback period calculation
- Solve for a different variable
  - ➢ Enter expected revenue and solve for IRR
  - ➢ Enter expected revenue and IRR; solve for NPV of after tax cash flow



Model can be obtained from following website: http://www.hydrogen.energy.gov/fc_power_analysis.html

Slide source: DOE Fuel Cell Technologies Office

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Thank You!

Additional Questions by Email:
Marc.Melaina@nrel.gov

Value Propositions for Food Industry

Stationary Power Fuel Cells for Combined Heat & Power (CHP) Applications

A 400-kW fuel cell (grey box) meets 85 percent of the energy needs of this Price Chopper supermarket in Albany. The installation reduces the building's carbon footprint by 71 tons, provides energy security for perishable items, and saves more than 4 million gallons of water each year. *(Photo taken from the Executive Summary of the New York State Climate Action Plan Interim Report)*

Slide source: DOE Fuel Cell Technologies Office

Case Study: Verizon

High-reliability CHP system providing primary and back-up power, heating and cooling for a telephone and data service facility.

Location	Verizon Central Office Building Garden City, NY
Date Installed	2005
Equipment	• Seven UTC 200-kW natural gas fired fuel cells • Two absorption chillers, one unfired heat recovery steam generator, natural gas and diesel engines.
Facility	292,000 sq ft.
Energy Savings	$0.5 million for the first five years
Benefits	• 11.1 million pounds of CO_2 offset per year • NO_X emissions reduced by 19 tons per year • 5.5 million gallons of water saved per year
Performance*	• Availability: 88% • Efficiency: Approaching 90%

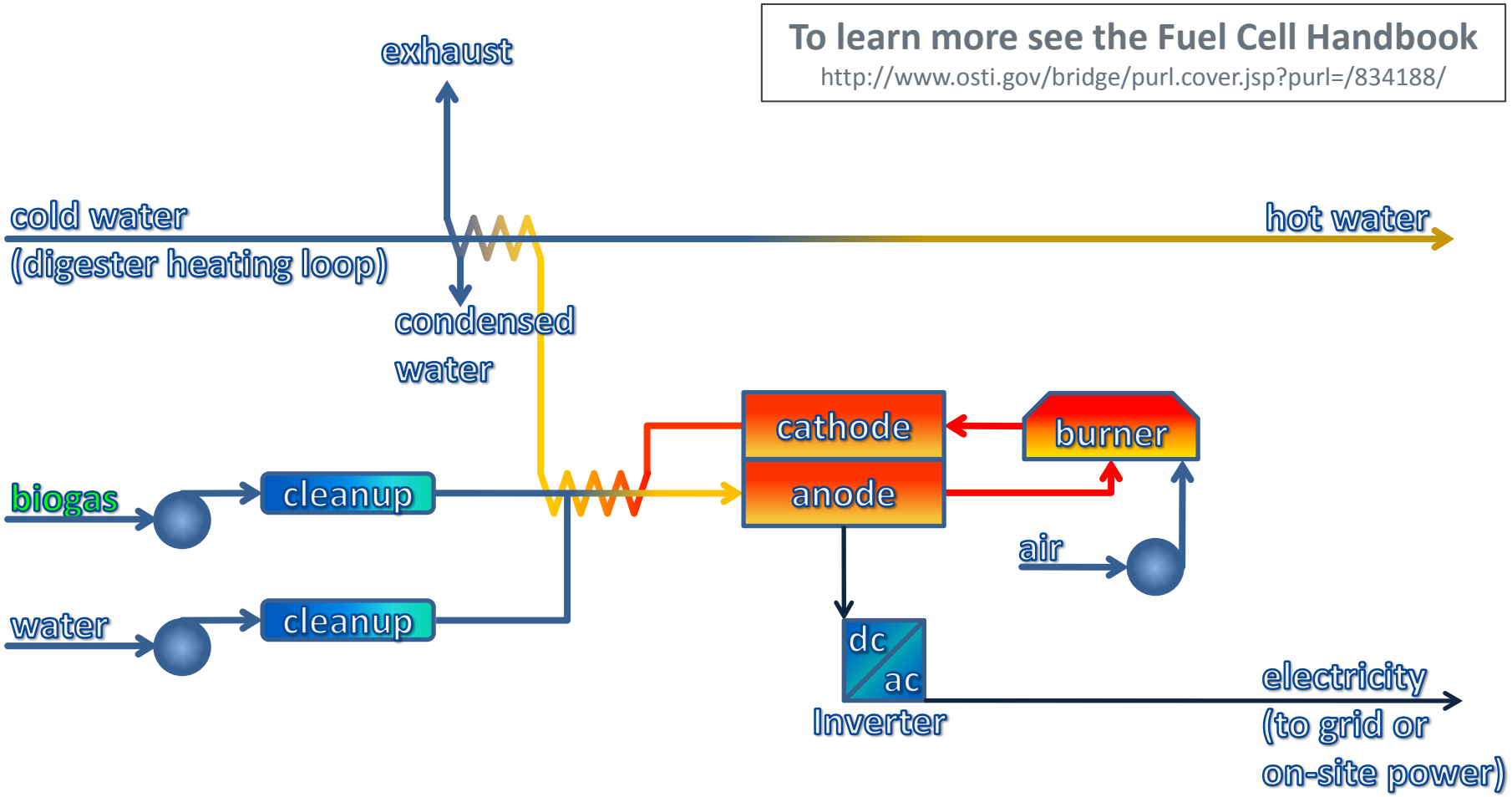
Contact: Jeremy Metz, 212-338-6405, Jeremy.metz@verizon.com

*Source: UTC Power

Verizon

Slide source: DOE Fuel Cell Technologies Office

Combined Heat & Power Molten Carbonate Fuel Cell System



Two products are recovered from this system:

- Heat (steam or water); this stream can be applied to maintain digester temperature.
- Electricity (typically base-load); production efficiency = 45 to 49% LHV